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Solar Mini-grid for Rural Electrification: A Case of Laprak Village

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Abstract

Nepal is heavily dependent upon traditional biomass and imported petroleum fuels in order to meet its energy demand. The use of traditional biomass fuels is especially dominant in the rural Nepal where there is limited access or no access to modern sources of energy such as petroleum fuels and grid electricity. The access to modern sources of energy in rural Nepal is limited due to the topography with harsh terrains, distributed settlement and limited demand. The expansion of the national electricity grid is very expensive with limited return and the cost of transportation of petroleum fuels is very high causing the fuels to be very expensive. Despite the cost, the rural villages are slowly shifting from the traditional biomass fuels to petroleum fuels which is not sustainable. In 2010, Nepal's electrification rate was only 53 percent (leaving 12.5 million people without electricity) and 76 percent depended on fuelwood for cooking (meaning 20.22 million people placed stress on Nepali forests for their fuel needs) [1]. Nepal has plenty of renewable energy sources such as solar, wind and hydro but it has not been able to harness energy from these resources to its full potential. It is very essential to realize the importance of available renewable energy sources and its development for sustainable energy development of the country.

This research aims to provide a sustainable renewable source of energy for rural electrification of Nepal. The research deals with the household energy consumption pattern and energy demand of a homogeneous rural community at Laprak village. It studies the feasibility of a stand-alone solar micro/mini grid as a sustainable energy source for the electrification of the village.

Keywords

Photovoltaic Solar Energy, Renewable energy, Solar grid, Solar village

1. Introduction

Energy is the basic requisite for the socio-economic development of a country. Access to reliable and affordable energy services are fundamental to reduce energy poverty by the development of indigenous and sustainable energy resources like hydropower, solar, wind, etc. Unless the energy sector is geared up for the efficient and indigenous resources, sustainable energy development cannot be achieved.

In 2010, Nepal's electrification rate was only 53 percent (leaving 12.5 million people without electricity) and 76 percent depended on fuelwood for cooking (meaning 20.22 million people placed stress on Nepali forests for their fuel needs) [1]. Although Nepal possesses a huge potential of renewable energy i.e. hydropower potential of 83,000 MW (42000 MW economically viable), solar potential of 4.7 kWh/m2/day but still the country has not been able to harness enough energy from the indigenous sources and is increasingly depending on imported fossil fuels. Total energy consumption in the year 2008/09 was about 9.3 million tons of oil equivalent (401 million GJ) in the country out of which 87% were derived from traditional resources, 12% from commercial sources and less than 1% from the alternative sources [2]. Also, residential sector is the major consumer of energy in Nepal. Residential sector consumes 89% of total energy and share of fuel wood is 86.5%. Fuelwood is used for cooking, heating, boiling water and other uses in households [2].

Majority of the population in Nepal lives in rural areas. Only 34% of the rural population have access to electricity [3]. This is due to the terrain topography and high cost for the expansion of national grid in rural areas. A stand-alone mini grid of renewable source could be more suitable for electrification of these rural areas. Various micro-hydro and small-scale solar home systems projects have been initiated within past few years by AEPC for the electrification of rural areas.

Laprak is a homogeneous Gurung Village which lies in Dharche Rural-Municipality, Gorkha District 14.7 km North East of Barpak. The village lies at an altitude of 2300m above the sea level with the population of 2161 and 529 households (CBS, 2011). Laprak has a warm and temperate climate with annual average temperature of 15.5ºC and annual precipitation of 1875mm.

After 2056 landslide in Laprak, the village was declared vulnerable but no attempts were made for the resettlement of the village. But after the massive earthquake in 2072, the village was severely effected and a joint effort was made by NRNA, NRA and the government of Nepal to resettle the the village at Gupsipakha, Laprak.

Gupsipakha is located approximately 3.5 kms South West of the old settlement of Laprak. It lies at an altitude of 2800m above the sea level and about 2 hours ascend from the old settlement. The new settlement at Gupsipakha covers an area of 18.2 hectors with 573 households and oriented towards Northern slope.

2. Objective

Main objectives:

- To analyze the feasibility of stand-alone solar mini-grid for sustainable energy development of Laprak

Specific Objectives:

- To study the current energy consumption pattern and determine the energy demand of Laprak.
- To analyze the benefit-cost of the solar grid.
- To perform triple bottom line analysis for the sustainability of the solar village.

3. Methodology

The particular research is about the study of household energy consumption pattern and sustainable energy development. The data required are both qualitative and quantitative. Hence, the research follows the Post-Positivist paradigm. The quantitative data are collected from the field survey and questionnaires and the qualitative data are collected from the observation and interviews with the participants and stakeholders. The data are then compiled in Excel to generate the required information for analysis. This paper investigates the sustainability using Triple Bottomline approach. Triple Bottomline analysis is a qualitative tool for the sustainability assessment of a system analyzing from the three aspects of sustainability i.e. Social, Economic and Environmental aspects.

4. Energy and Climate Change

Current patterns of energy production and consumption are unsustainable and threaten local, regional, and global environments. Excessive uses of biomass and fossil fuels have particularly negative environmental impacts, contributing to GHG emissions, land degradation, air pollution, and water and soil acidification.

Nepal is responsible for only about 0.025% of annual global GHG emissions, but is highly vulnerable to climate change. Increasing temperatures, especially in mountain areas, is resulting in the recession of glaciers and snowfields. This will affect the supply of water for irrigation, household use, and hydroelectricity.

In addition, receding glaciers often leave behind large glacial lakes that can break through terminal moraines and cause catastrophic floods. Global climate change will also result in shifting monsoon precipitation patterns that will threaten Nepal's current agricultural practices, infrastructure, and bio-diversity [4].

5. Photovoltaic Solar Energy

Photovoltaic Solar Energy can be defined as energy source that converts light directly into electricity without any harmful emissions. The conversion of solar radiation into electricity occurs due to the photovoltaic effect, which was observed by the first time by Becquerel in 1839. This effect occurs in materials known as semiconductors, which present two energy bands, in one of them the presence of electrons is allowed (valence bad) and in the other there is no presence of them, i.e., the band in completely "empty" (conduction band). The semiconductor material more commonly used is the silicon, second most abundant element on Earth. Its atoms are characterized by having four electrons that connect to its neighbors, creating a crystal network.

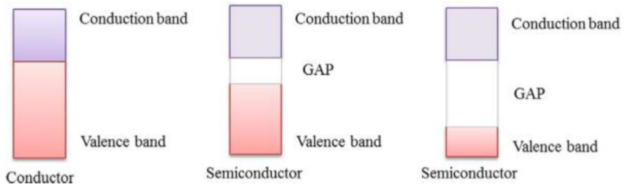

Figure 1: Band of valence, band gap (GAP) and the conduction band: insulator, conductor

The function of sunlight on the photovoltaic effect is to supply an amount of energy to the outermost electron to make it possible for him to move from the valence band to the conduction band in the material, thereby generating electricity. As in the case of silicon, specifically, it is needed 1.12 eV (electro volts) for electrons to exceed the GAP. Further, according to, the semiconductor material must be able to absorb a large part of the solar spectrum [5].

Virtually all photovoltaic devices incorporate a PN junction in a semiconductor, which through a photo voltage is developed. These devices are also known as solar cells or photovoltaic cells. The PN junction is the main part of the cell where the light receiving portion is the N-type material in the part below this the material is P-type.

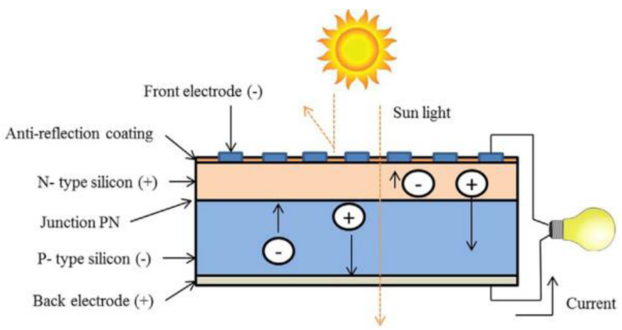

Figure 2: Photovoltaic Cell

Compared to conventional power generation sources, such as those using fossil fuels, photovoltaic technology does not bring the serious environmental problems that these sources cause during generation, such as climate change, global warming, air pollution, acid rain and so on. Another advantage in relation to fossil fuels is that solar energy does not need to be extracted, refined or transported to the generation site, which is close to the load. However, during its life cycle, it consumes a large amount of energy and emits some greenhouse gases in some stages (manufacturing process of solar cells, assembly of photovoltaic modules and transport of material, among others). Photovoltaic technologies, consume per unit of electricity produced, 64 times more material resources, 7 times more human resources and 10 times more capital than nuclear technology [5]. Although this data is biased, this is a clear indication of the extreme inefficiency of PV technologies in regions of moderate sunshine to help achieve the goal of providing a resource-efficient, efficient electricity supply system. Due to the intermittent nature of electricity production in these regions, parallel electricity supply infrastructure needs to be provided.

In relation to other renewable sources, photovoltaic solar energy presents a lower incidence of damages to the environment where it is being generated, which does not occur with the energy produced by the hydroelectric plants, where for the construction of hydroelectric plants the course of the river is changed and extensive areas of production of food and forests are flooded. Another important factor is the cost of operation, which for hydraulic power generation is high compared to the cost of operating a solar plant. Despite the decrease in generation during cloudy days, energy from the sun is abundant, while the volume of water in the dams during periods of drought is limited. If compared to wind energy, photovoltaic solar energy is silent and can be generated in urban areas since panels can be installed on the roof.

Despite its limitations, the photovoltaic power generation systems allow the installation of a shortterm power plant, with the possibility to generate several MW in less than a year. As the environmental impacts, they are minimal, photovoltaic systems remove the need for preliminary studies that require long-term assessment, unlike the highly polluting systems.

Photovoltaic solar energy is useful for various applications such as space crafts, water pumping, street lighting, telecommunications, satellites, water desalination, weather monitoring and building integrated photovoltaic system.

5.1 Elements of Photovoltaic solar Energy System

A typical photovoltaic solar system consists of four basic elements: Photovoltaic module, charge controller, the inverter and battery when necessary.

The photovoltaic module consists of photovoltaic cells, i.e., the surfaces that generate electricity, which convert directly solar energy into electricity. These surfaces have no moving parts to wear out or suffer breakdowns and works without the use of fuel without vibrations without noise and without harming the environment.

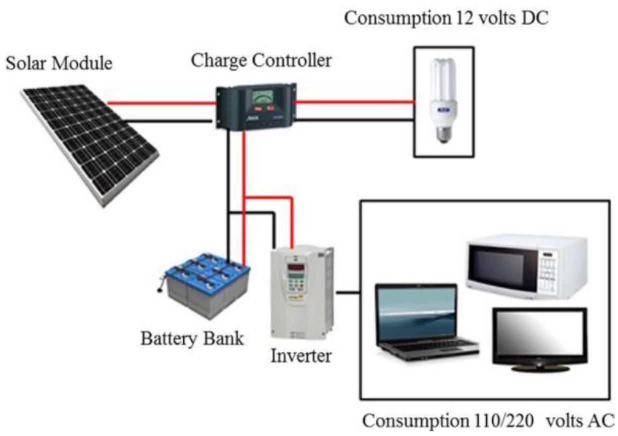

Figure 3: Typical System of Photovoltaic Solar Energy

As for the charge controller, it has the function to preserve the batteries from being overcharged or discharged completely, increasing its useful life. The inverter, in turn, is responsible for converting the power generated by photovoltaic panels (electricity generating DC – DC) to alternating current – AC voltage levels and network frequency. Batteries are used in photovoltaic systems to store the surplus produced by the modules to be utilized at night or on days with low sunshine or overcast.

6. Solar Village Concept

”Solar Village” is a cluster of remote villages where no modern facilities are available and solar power is provided to supply water and power to uplift their standard of living [6].

Main Components of Solar Village

- The “Envelope” Greenhouse
- Solar Energy
- Solar thermal
- Solar PV electric
- The Pumping of Water
- Water Disinfection

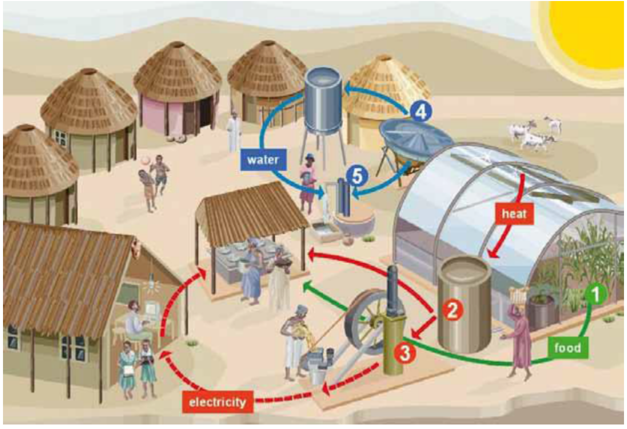

Figure 4: Solar Village

7. Nepal’s Current Energy Scenario

Nepal has only 86 kW h of energy consumption per person annually, which is very low when compared to the global average of more than 3000 kW h [7]. Electricity contributes only 2.8total energy demand of the country in Nepal whereas traditional biomass like firewood (71.06%), dung cake (5.08%), and agricultural residue (3.51%) fulfills most of the remaining energy need. Despite not having any fossil fuel reserves, the dependency upon the petroleum products for energy is 12% which tops all the other sources except biomass [8].

This clearly shows that our current energy consumption pattern is highly dependent upon traditional and imported energy sources which are not sustainable. Hence, efforts are to be made for the development of local and more sustainable source of energy.

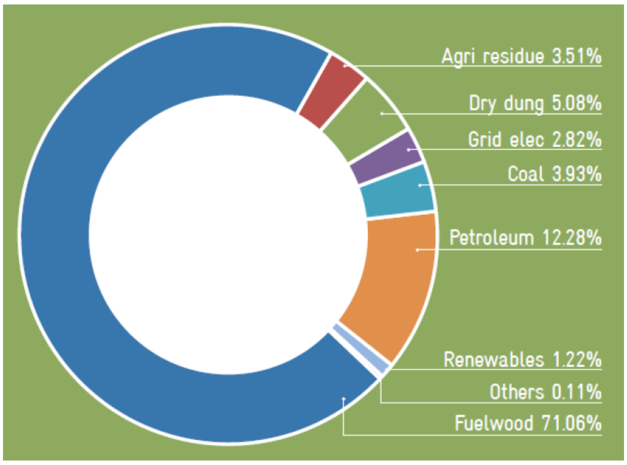

Figure 5: Energy consumption by fuel type (2011/2012)

Nepal has good potential to establish hydropower plants because of its terrain and hydrology. The theoretical hydroelectric potential has been estimated to be as high as 83,000 MW of which 42,000 MW are considered to be technically and economically feasible. Yet, Nepal is not being able to utilize its hydropower potential to its optimum benefit. Also its topography with steep mountains and hills in combination with the scattered settlements makes supply of electrical energy through centralized grids very difficult and costly.

Therefore, there is a need for the development of decentralized and sustainable energy system such as Micro Hydro (MH), Photovoltaic Solar Grids, Wind, etc. to access and supplement the current energy shortage.

8. Solar Potential in Nepal

Nepal is situated in south Asia between latitudes of 26°22_N to30°27_N and longitudes of 80°4_E to 88°12_E. It has a very diverse topography rising from less than 100m in the south to beyond the perpetual snow line peaks over 8000m in North. Climatic conditions including precipitation, wind speed, temperature changes with altitude. This diversity makes human settlement condition and solar radiation pattern diverse in whole Nepal. The average Global Solar Radiation (GSR) to this latitude ranges from 3.6 to 6.2 kW h/m2/day with over 300 bright sunny days per year and 6.8 h/day of bright sunshine with average solar intensity of4.7 kW h/day [9].

9. Results and Discussion

This section presents the results of primary energy data survey which includes the final energy consumption pattern of residential sector by fuel use type as well as end use.

Table 1 shows the overall final energy demand of residential sector of Laprak Village. It is found that a total energy of 58136.69 GJ is consumed in the year 2018. About 56470.58 GJ of energy is derived from firewood which is a traditional biomass source collected from the nearest community forest. The imported LGP contributes 1442.37 GJ and only 224.74 GJ of energy is derived from non-renewable sources such as Micro-hydro and Solar.

Figure 6 shows the final energy consumption of Laprak Village by fuel type. It shows that firewood is the predominant source of energy in the village which accounts a major share of energy consumed (97%). Recently LPG is also gaining popularity with the fuel share of 3% and growing in trend while the share of other sources of energy such as electricity from micro hydro and solar are negligible. This is due to the fact that the electricity generated from these renewable sources are only limited to lighting purpose.

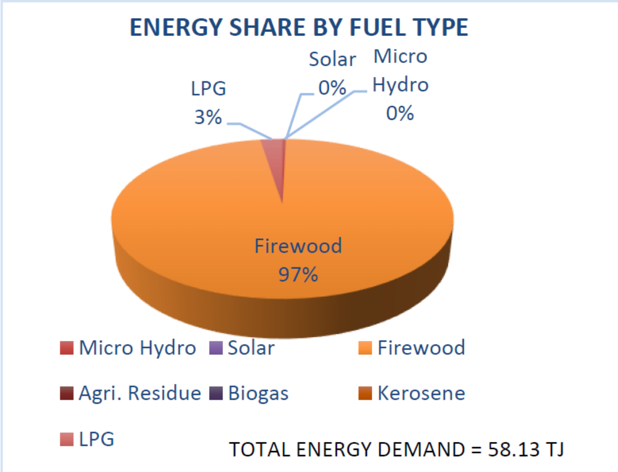

Figure 6: Final Energy Share by Fuel Type

Figure 7 shows that cooking is the most energy intensive end use for the village of Laprak which accounts for 88% (50.8 TJ) of the total energy demand. Firewood is the predominant fuel for cooking in the village which accounts for 97% (49.38 TJ) of the energy demand for cooking followed by LPG 3% (1.44 TJ) and growing. Electricity has not yet been able to be utilized for the cooking purpose due to low generation capacity of the hydro power plant.

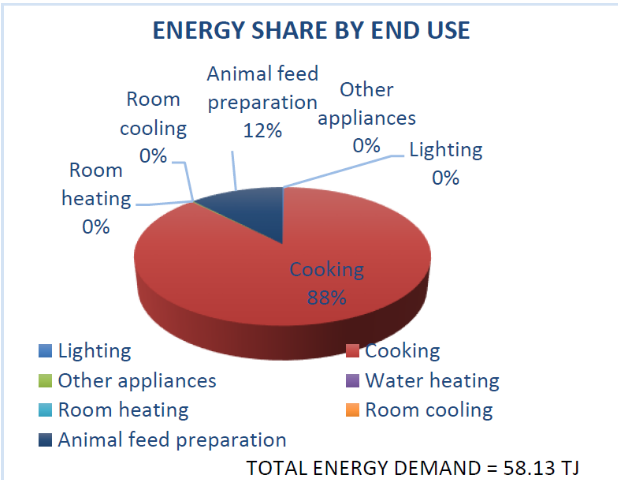

Figure 7: Final Energy Demand by End Use

Table 1: Final Energy Demand (GJ)

	Electricity (Micro Hydro)	Solar	Firewood	Agri. Residue	Biogas	Kerosene	LPG	Total
Lighting	111.19	2.09	-	-	-	-	-	113.29
Cooking	-	-	49381.08	-	-	-	1442.37	50823.46
Other appliances	110.46	-	-	-	-	-	-	110.46
Water heating	-	-	-	-	-	-	-	0.00
Room heating	-	-	-	-	-	-	-	0.00
Room cooling	-	-	-	-	-	-	-	0.00
Animal feed preparation	-	-	7089.49	-	-	-	-	7089.49
Alcohol Preparation	-	-	-	-	-	-	-	0.00
Total	221.65	2.09	56470.58	0.00	0.00	0.00	1442.37	58136.69

Figure 8 shows that electricity consumption per capita for Laprak village is around 22 kWh. This is almost one-third of the national average of 64 kWh and very low as compared to the capital of Kathmandu i.e. 208.4 kWh. The figure is very far from the target set by the SDG-7 of Nepal to reach around 700 kWh per capita electricity consumption in 2030. In order to achieve the goal, a serious measure should be implemented in time, especially in the rural settings like Laprak where there is no accessibility of grid electricity.

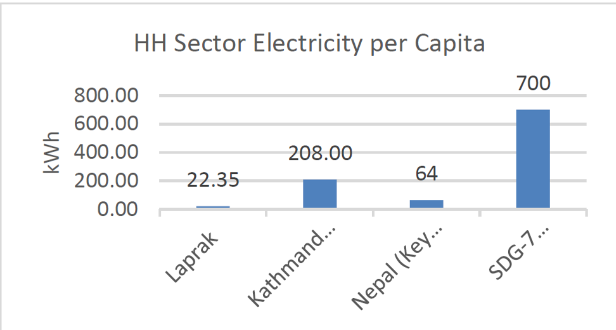

Figure 8: Household sector energy per capita

10. Scenario Analysis

This section shows the results of scenarios developed from the primary data survey and secondary data on demography, technologies and resources. The results of the scenario that have been analyzed are described to give the effects of certain policy and technologies interventions. Table shows the descriptions of the scenarios that have been developed in this study.

Figure 9 shows that the current energy demand is 58.13 TJ and the demand will increase to 65.97 TJ without any intervention by 2030. But the demand can be reduced to 15.95 TJ by 2030 with AEL Scenario and 24.42 TJ with SDG Scenario.

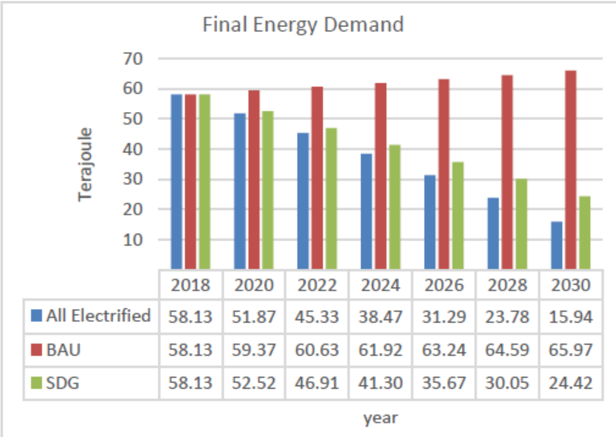

Figure 9: Final Energy Demand

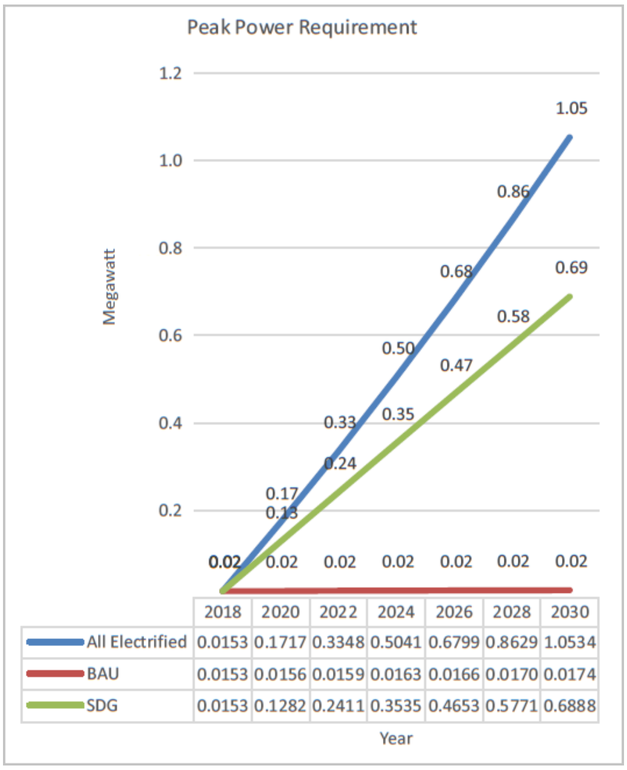

Figure 10: Peak power requirement

Table 2: Scenario Description

S.N.	Scenario	Abbreviation	Description
1	Business as Usual	BAU	• Consumption pattern continues as exiting • Energy demand increases with respect to population growth • Energy intensity and energy mix remains the same.
2	All Electrified	AEL	• Energy demand increases with respect to population growth. • Traditional energy sources like fuel-wood, agricultural residue and fossil fuel like LPG gradually replaced by clean source of energy like electricity and solar by the year 2030.
3	Sustainable Development Goal	SDG	• Energy demand increases with respect to population growth. • Fuel-wood for cooking is gradually reduced to 10% according to SDG which is replaced clean source of energy like electricity and solar by the year 2030. • Other energy sources demand grows with respect to population growth

Figure 10 shows that the peak power requirement will increase from current 0.02 MW to 0.7 MW in SDG scenario and reach 1.05 MW in AEL scenario by 2030.

11. Conclusion

The study showed that there is a huge difference in the energy consumption pattern in urban and rural areas of Nepal. Rural areas of Nepal like Laprak consume more energy than the Urban because of the use of inefficient fuels. The traditional biomass fuels are not only inefficient but also contributes to GHG emission and has negative impact upon the users. Thus, there is a need for the energy system to shift towards a sustainable and clean energy.

Though Nepal has good potential in developing Hydropower plants due to its terrain and hydrology, due to lack of high investments, it has not been utilized to its optimum benefits. With the average Global Solar Radiation (GSR) of 3.6 to 6.2 kW h/m2/day and over 300 bright sunny days per year and 6.8 h/day of bright sunshine with average solar intensity of 4.7 kW h/day, Nepal has good potential for the development of stand-alone solar PV grids in the rural areas having no access to grid electricity.

From the above figures, it is clear that the energy demand of Laprak village is dominated by traditional firewood in the current scenario which is inefficient and contributes to higher GHG emission. The consumption of LPG is not sustainable as the cost is higher than the maximum retail price due to the difficulty in transportation. Electricity generation is very low which is only sufficient for 14 hours of lighting with limited electrical appliance and some small-scale industries. The demand is going to increase if the village is to be electrified 24 hours a day. It shows that the current energy situation of the village is not sustainable. Hence, there is a need for fuel shift from inefficient firewood and imported LPG to cleaner and renewable source of energy like solar and hydro. If the village is to be electrified with a standalone Solar PV, a Mini-grid of capacity of 0.7 megawatt-year is required to be installed with proper resource assessment and feasibility analysis.

12. Further works

Feasibility and benefit-cost analysis of the stand-alone solar mini-grid for Laprak Village.

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